Building a better nanoparticle reactor

On a recent day in December, Peter Kong and his team at Idaho National Laboratory fired up their newly designed plasma reactor to more than 10,000 degrees Celsius. While feed lines pushed sand-like silica particles into the top of the noisy reactor, a fine layer of white powder began accumulating in the collection chamber at the bottom. The powder doesn't look like much, but each granule is a nanoparticle, too tiny to be viewed under an ordinary microscope. Unseen in the center of the reactor, the stream of silica feedstock is completely vaporized, forming the miniscule particles as it exits and cools.

Nanoparticles are tiny agglomerations of atoms. Because the particles are so small, their surfaces play a huge part in interactions, giving them a number of unique chemical properties. Suspended in paint, nanoparticles can help create anti-corrosive coatings. Silver nanoparticles have been shown to have antimicrobial properties. Fused together, nanoparticles can make stronger materials than the alloys from which they are produced.

A cloud of alumina, or aluminum oxide, nanoparticles exits INL's modular plasma reactor.

One day, Kong hopes to transform industrial nanoparticle production by creating a reactor that can transform feedstock like beach sand into uniformly-sized silica nanoparticles. Working with such unprocessed raw materials is tricky, but the Idaho National Laboratory materials scientist and his team are developing a solution - a novel plasma reactor, one that holds feedstock at higher temperatures and longer times. The goal, Kong says, is to reduce up-front processing of raw materials while boosting nanoparticle output. "We are creating a single-step process to produce nanoparticles in large quantities," says Kong. "We want it to be green, to be able to transform low-cost, large-sized feed material with much better efficiency."

Transforming the approach

A scanning electron micrograph of alumina nanoparticles. Roughly 80 percent of the particles are less than 10 nanometers in size.

Although nanoparticles show great promise for a number of applications, it is still difficult to make them in large quantities. Common manufacturing processes include grinding particles up to make them smaller, changing their composition with chemical reactions, or heating them up to make them smaller. But producing large quantities can be expensive. Feedstock needs to be pre-processed to make it small. Chemical processes produce a number of byproducts. Manufacturing methods often must be tailored to suit the composition of the source material.

Engineered properly, Kong says, plasma processing offers a unique solution. Plasma reactors are advanced furnaces that can heat a gas to more than 10,000 degrees Celsius, creating roiling plasma that vaporizes ground-up feedstock. As the gasified material exits the reactor, it quickly cools. Atoms of the material stick together, forming nanoscale spheres, platelets and faceted balls.

While conventional plasma reactors are already used to produce nanoparticles, refining feedstock so it is pure and small enough to be vaporized is expensive. What's more, even with ideal feedstock, current plasma arc technologies transform only a small fraction of raw material into nanoparticles. The trick to improving output, Kong says, is keeping the stream of feed material in the plasma long enough for it to completely vaporize.

To keep feed material in for long times, Kong devised a modular reactor that produces a plasma arc of adjustable length. Commercial reactors have plasma residence times of only a few milliseconds, which is not enough to vaporize large, solid feed particles. By changing the reactor geometry, Kong and his team boost the time materials stay in the plasma, converting 100 percent of large, solid feedstocks like silica and alumina into nanoparticles.

"This is a completely new design," says Noel Vanier of PPG Industries, which is collaborating with Kong on developing the reactor. "The big plan is to take this reactor from a lab oddity that can produce a few grams of stuff to a commercial process that can produce millions of pounds a year."

Developing a pilot plant

Kong has built a career developing plasma reactor systems to process radioactive waste, convert natural gas to liquid hydrocarbons, and produce chemical hydrides for hydrogen storage. Creating a nanoparticle plasma reactor is a bit different. "It's not particularly tricky," Kong says, "but it's definitely an engineering design challenge."

A pilot production facility is set to launch next year, and Kong and his team are refining the laboratory reactor design. In recent months, the team has made provisions to rapidly rotate the plasma arc column, creating a funnel that keeps the feed particles away from the arc channel wall. The redesign will be important in boosting the output of the reactor as feed particles can easily stick to surfaces of the arc channel when they are partially melted and before complete vaporization.

With more refinement, Kong says, the team's enhanced reactor can be used for commercial-scale production of nanoparticles for alloys, catalysts, pigments and structural materials, among many other applications. So far, the reactor has created silica and alumina nanoparticles, but once perfected, the scaled-up pilot reactor could produce industrial quantities of nanoparticles regardless of composition. Transforming beach sand into nanoparticles is still on the horizon, Kong says, "but we're making tremendous progress."

General Contact:
Nicole Stricker, (208) 526-5955

Feature Archive

INL materials researchers (left to right) Larry Zuck, Dean Harding, Peter Kong, Brent Detering and Jon Grandy stand around the group's plasma hybrid reactor, which converts large solid particles into nanoscale equivalents.